Federal Aviation Administration

DOT/FAA/AM-08/12
Office of Aerospace Medicine
Washington, DC 20591

Understanding the Human Factors Associated With Visual Flight Rules Flight Into Instrument Meteorological Conditions

Cristy Detwiler
Kali Holcomb
Carla Hackworth
Civil Aerospace Medical Institute
Oklahoma City, OK 73125

Scott Shappell
Clemson University
Clemson, SC 29634

May 2008

Final Report

OK-08-1997

NOTICE

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
DOT/FAA/AM-08/12		

4. Title and Subtitle	5. Report Date
Understanding the Human Factors Associated With Visual Flight Rules Flight Into Instrument Meteorological Conditions	May 2008
	6. Performing Organization Code
7. Author(s)	8. Performing Organization Report No.
Detwiler C,[1] Holcomb K,[1] Hackworth C,[1] Shappell S[2]	
9. Performing Organization Name and Address	10. Work Unit No. (TRAIS)
[1]FAA Civil Aerospace Medical Institute P.O. Box 25082 Oklahoma City, OK 73125 [2]Clemson University Clemson, SC 29634	11. Contract or Grant No.
12. Sponsoring Agency name and Address	13. Type of Report and Period Covered
Office of Aerospace Medicine Federal Aviation Administration 800 Independence Ave., S.W. Washington, DC 20591	
	14. Sponsoring Agency Code

15. Supplemental Notes

Work was accomplished under approved task AM-B-06-HRR 521.

16. Abstract

Visual Flight Rules (VFR) into Instrument Meteorological Conditions (IMC) accidents are a major concern in the aviation industry. More than 70% of the fatal weather-related accidents involved General Aviation (GA) pilots operating under visual flight rules (VFR) that continued into IMC. The purpose of this study was to pair GA accident causal factors that had been classified with the Human Factors Analysis and Classification System (HFACS) categories and traditional demographic data in an effort to present a more complete picture of VFR flight into IMC accidents. To accomplish this, GA accidents associated with VFR flight into IMC were examined to determine if there were any causal factors that set these accidents apart from the rest of GA (RoGA) accidents. GA accident data (14 CFR Part 91) from 1990-2004 were analyzed. The dataset was divided into accidents that had VFR into IMC (VFR-IMC; N = 609) cited as a cause or factor versus the rest of the GA accidents (RoGA; N = 18,528). Analyses were performed examining the human error associated with these accidents. The results indicated that skill-based errors were more prevalent in RoGA than in VFR-IMC (odds ratio = 4.167, χ^2 = 332.531, p <.001). VFR-IMC pilots were more likely to commit a decision error (odds ratio = 2.062, χ^2 = 77.961, p <.001); experience a perceptual error (odds ratio = 3.179, χ^2 = 118.350, p <.001); and commit a violation (odds ratio = 29.960, χ^2 = 2454.198, p <.001) than RoGA. The injury severity for VFR-IMC accidents was much greater than for RoGA (80.3% vs. 18.8%). RoGA pilots held a higher number of multiple certificates and earned more flight hours across the board than the VFR-IMC pilots. These data provide a more detailed view of the VFR into IMC accidents and will facilitate the development of future data-driven intervention strategies. Current interventions include weather cameras and other pilot aids for decision making with regard to weather.

17. Key Words	18. Distribution Statement
Weather-related accidents, Visual Flight Rules (VFR) into Instrument Meteorological Conditions (IMC), HFACS, General Aviation (GA)	Document is available to the public through the Defense Technical Information Center, Ft. Belvior, VA 22060; and the National Technical Information Service, Springfield, VA 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	16	

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

Contents

INTRODUCTION 1
HFACS 2
Purpose 2
METHOD 2
Human Factors Analysis 2
RESULTS 2
Part I. Comparisons Between VFR-IMC and RoGA 2
Demographics 2
Human Error 4
Part II. In-Depth Examination of VFR-IMC Accidents 5
Demographics 5
Human Error 6
DISCUSSION 7
The Next Step 9
REFERENCES 10

Glossary of Terms

Skill-based errors (SBEs). SBEs occur with little or no conscious thought. SBEs can be thought of as "doing" errors. For instance, little thought goes into turning one's steering wheel or shifting gears in an automobile. Similarly, basic flight skills such as stick and rudder movements and visual scanning refer more to how one does something rather than where one is going or why. The difficulty with automatic behaviors is that they are particularly susceptible to attention and/or memory failures. As a result, SBEs such as the breakdown in visual scan patterns, inadvertent activation/deactivation of switches, forgotten intentions, and omitted items in checklists often appear. Even the manner (or skill) with which one flies an aircraft (aggressive, tentative, or controlled) can affect safety.

Decision errors (DE). One of the more common error forms, DEs, represent conscious, goal-intended behavior that proceeds as designed, yet the plan proves inadequate or inappropriate for the situation. These errors typically manifest themselves as poorly executed procedures, improper choices, or simply the misinterpretation and/or misuse of relevant information.

Perceptual errors (PE). While DE and SBEs have dominated most accident databases and have, therefore, been included in most error frameworks, the third and final error form, PE, has received comparatively less attention. Perceiving errors arise when sensory input is degraded, or "unusual" as is often the case when flying at night, in the weather, or in other visually impoverished environments. Aircrew run the risk of misjudging distances, altitude, and descent rates, as well as responding incorrectly to a variety of visual/vestibular illusions when faced with imperfect or incomplete information.

Violations (V). Routine Vs tend to be habitual by nature and are often enabled by a system of supervision and management that tolerates such departures from the rules (Reason, 1990). Often referred to as "bending the rules," the classic example is that of the individual who drives his/her automobile consistently 5-10 mph faster than allowed by law. While clearly against the law, the behavior is, in effect, sanctioned by local authorities (police) who often will not enforce the law until speeds in excess of 10 mph over the posted limit are observed.

There are also exceptional Vs, which are isolated departures from authority, neither typical of the individual nor condoned by management. For example, while authorities might condone driving 65 in a 55 mph zone, driving 105 mph in a 55 mph zone would almost certainly result in a speeding ticket. It is important to note that while most exceptional Vs are appalling, they are not considered "exceptional" because of their extreme nature. Rather, they are regarded as exceptional because they are neither typical of the individual nor condoned by authority.

Adverse mental states (AMS). Being prepared mentally is critical in aviation. AMS include the loss of situational awareness, mental fatigue, circadian dysrhythmia, and pernicious attitudes such as overconfidence, complacency, and misplaced motivation that negatively impact decisions and contribute to unsafe acts.

Adverse physiological states (APS). Equally important however, are those APS that preclude the safe conduct of flight. Conditions such as spatial disorientation, visual illusions, hypoxia, illness, intoxication, and a whole host of pharmacological and medical abnormalities are known to affect performance. It is important to understand that conditions like spatial disorientation are physiological states that cannot be turned on or off – they just exist. As a result, these APS often lead to the commission of unsafe acts like PEs. For instance, it is not uncommon in aviation for a pilot to become spatially disoriented (APS) and subsequently misjudge the aircraft's pitch or attitude (PE), resulting in a loss of control and/or collision with the terrain.

Physical/mental limitations (PML). PML includes those instances when necessary sensory information is either unavailable, or if available, individuals simply do not have the aptitude, skill, or time to safely deal with it. There are instances when an individual simply may not possess the necessary aptitude, physical ability, or proficiency to operate safely.

Crew resource management (CRM). There are occasions when crew members may not fully understand each other's intentions. When this occurs, confusion (AMS) and poor decisions in the cockpit can result. CRM includes the failures of both inter- and intra-cockpit communication, as well as communication with Air Traffic Control (ATC) and other ground personnel. CRM also includes those cases when individuals fail to coordinate activities before, during, and after a flight.

Personal readiness (PR). This category includes those occurrences when individuals have not abided by crew rest requirements, have improperly self-medicated, or have not ensured that they are prepared for flight

Technological environment (TE). TE encompasses the design of equipment and controls, display/interface characteristics, checklist design, and automation. Automation designed to improve human performance can have unforeseen consequences. For example, highly reliable automation has been shown to induce AMS such as overconfidence and complacency, resulting in pilots following the instructions of the automation even when "common sense" suggests otherwise.

Understanding the Human Factors Associated With Visual Flight Rules Flight Into Instrument Meteorological Conditions

The 14 CFR Part 91 personal flight was not on a flight plan. Visual meteorological conditions prevailed at the time of the accident....An individual representing N9523P contacted the Princeton Automated Flight Service Station (AFSS) at 0455 on the morning of the accident. The individual requested a visual flight rules (VFR) weather briefing from GPZ [Grand Rapids/Itasca County Airport] to STC [St. Cloud Regional Airport], departing at 0600. The caller was advised of the current and forecasted conditions along the proposed route of flight, as well as of the Aeronautical Meteorological Information (AIRMET) in effect at the time. An abbreviated weather briefing was requested from Princeton AFSS at 0541. Proposed departure time was stated as 0600. During his initial statement to the briefer, the caller noted that conditions at GPZ were marginal at the time. He noted that current conditions at GPZ were about 2,800 feet overcast and that he was "**hoping to slide underneath it and then climb out.**" He requested current conditions at STC and any pilot reports. He was advised of the STC conditions and that no pilot reports were on file across the state at that time.

Final Report: The Cirrus SR-22 aircraft was destroyed upon impact with trees and terrain following a loss of altitude during a turn. The accident site was located in relatively level, wooded terrain. The surrounding area was sparsely populated and heavily wooded. The accident occurred prior to civil twilight and marginal VFR weather conditions were reported at the departure airport. ***Cause Report***: Spatial disorientation experienced by the pilot, due to a lack of visual references, and a failure to maintain altitude. Contributing factors were the pilot's improper decision to attempt flight into marginal VFR conditions, his inadvertent flight into instrument meteorological conditions, the low lighting condition (night) and the trees.

—NTSB accident report: CHI03FA057

Introduction

While weather-related general aviation (GA) accidents represented a relatively small percentage of the accidents in 2005, they accounted for nearly 14% of the fatal accidents involving fixed-wing aircraft with a gross weight less than 12,500 lbs. Moreover, two-thirds of weather-related accidents resulted in a fatality. More than 70% of the fatal weather-related accidents involved GA pilots operating under visual flight rules (VFR) that continued into instrument meteorological conditions (IMC) [Aircraft Owners and Pilots Association Air Safety Foundation (AOPA-ASF), 2006].

So why would a pilot fly into adverse weather, knowing the hazards associated with such decisions? After all, every pilot is taught the fundamentals of weather early in training – including how to avoid it by obtaining pre-flight weather briefings, as well as recognizing hazardous weather conditions in-flight, either through direct viewing outside the cockpit or with the use of on-board weather radar in appropriately equipped aircraft. In fact, Title 14 of the Code of Federal Regulations (CFR) Part 91.103 advises that all pilots flying instrument flight rules (IFR) or out of the airport area should be aware of weather reports and forecasts prior to initiating a flight (FAA, 2006).

One explanation could be that pilots continue flying into poor weather and simply fail to realize the imminent danger (Batt & O'Hare, 2005). Goh and Wiegmann (2001) have suggested that it may be that the decision to proceed into adverse weather is simply the end result of poor situation awareness, hazardous risk perception, motivational factors, or simply improper decision-making.

On the other hand, it may be that sufficient or adequate weather information is either unavailable or simply not used. Extracting critical facts from multiple sources of weather information can be challenging for even the experienced aviator (Parson, 2006). Moreover, in the absence of weather displays, en route weather information is available only to the extent that a pilot seeks it out.

To assist pilots with preflight weather planning and in-flight decision-making, the FAA recently released a guide for GA pilots (FAA, 2005). The goal was to provide guidance to pilots that have little weather experience, since it appears that many fatal weather-related accidents tend to occur when pilots have between 50 and 350 total hours of flight experience (Craig, 2001).

In the end, no single explanation seems to account for all VFR flight into IMC accidents. Just as experience, as defined by simple flight hours, cannot explain all VFR flight into IMC; neither can motivational factors, poor situation awareness, lack of knowledge, or poor pilot decision-making alone account for these accidents. Rather, it is probably a combination of all these issues, and perhaps more, that contribute to what accident investigators refer to as VFR flight into IMC (Goh & Wiegmann, 2002).

The dilemma is that few studies have fully determined why a pilot would fly into IMC when limited, by training, to fly under VFR. This is not to say that determined

efforts by private and government organizations have not been conducted to address this issue; it is just that most have not investigated all of the causal and contributory factors associated with these accidents. Instead, they have typically focused on a few demographic variables or more conceptual human components, such as the loss of situation awareness.

HFACS

Beginning in 1998, the FAA initiated an effort to analyze all United States (U.S.) civil aviation accidents with Human Factors Analysis and Classification System (HFACS), a human error taxonomy used by aviation and other high-risk industries to identify accident and incident causal factors attributed to humans at the operator, supervisory, and organizational levels.

Although originally developed for use within military aviation, in recent years HFACS has proven useful in identifying human causal factors associated with general and commercial aviation (Detwiler, Hackworth, Holcomb, Boquet, Pfleiderer, Wiegmann, & Shappell, 2006; Shappell, Detwiler, Holcomb, Hackworth, Boquet, & Wiegmann, 2007; Wiegmann, Faaborg, Boquet, Detwiler, Holcomb, & Shappell, 2005). A complete description of HFACS is provided elsewhere (Wiegmann & Shappell, 2003); however, a summary of those causal factors associated with general aviation is provided in the Glossary.

Purpose

The purpose of this study was to pair GA accident causal factors classified with HFACS with traditional demographic data (whether a flight plan was filed, a weather briefing was obtained, etc.) in an effort to present a more complete picture of VFR flight into IMC accidents. To accomplish this, GA accidents associated with VFR flight into IMC were examined to determine if there were any potential predictors or causal factors that set these accidents apart from the rest of GA (RoGA) accidents.

Method

GA accident data (i.e., 14 CFR Part 91) from calendar years 1990-2004 were obtained from databases maintained by the National Transportation Safety Board (NTSB) and the FAA's National Aviation Safety Data Analysis Center (NASDAC, now known as Aviation Safety Information Analysis and Sharing, ASIAS). Only final reports involving fixed- and rotary-wing aircraft associated with aircrew error were included in this study. Accidents that were classified as having "undetermined causes" and those attributed to sabotage, suicide, or criminal activity (e.g., stolen aircraft) were excluded.

Of the 19,137 accidents included in this study, VFR flight into IMC (referred to as VFR-IMC) was cited as a cause or contributing factor by the NTSB in 609 cases. The remaining 18,528 comprised the comparison group of accidents referred to as RoGA.

Each accident within the database contains a variety of demographics describing such situational factors as the environment (weather, lighting, etc.), aircraft (make, model, etc.), and aircrew (flight time, ratings, etc.). In addition, accidents were selected that were associated with specific causal/contributory factors attributed to aircrew error.

Human Factors Analysis

Although the original HFACS framework contains 19 causal categories, most GA accidents involved only the lower two tiers of HFACS (Unsafe Acts of Operators and Preconditions for Unsafe Acts), since rarely are supervisory or organizational causal factors cited in the accident record. Within those tiers are 10 causal categories that are included in this study: skill based errors (SBE), decision errors (DE), perceptual errors (PE), violations (V), adverse mental states (AMS), adverse physiological states (APS), physical/mental limitations (PML), crew resource management (CRM), personal readiness (PR), and technological environment (TE).

Pilots were recruited from the Oklahoma City area as subject matter experts (SMEs). Each pilot was provided roughly 16 hours of instruction on the HFACS framework, which included didactic lecture and practice (with feedback) using the HFACS framework with NTSB and NASDAC accident reports. After training, the pilot-raters were randomly assigned accidents so at least two separate pilot-raters independently analyzed each accident.

After the pilot-raters assigned their initial codes (i.e., SBE, DE, V, etc.), the two independent ratings were compared. Where disagreements existed, the corresponding pilot-raters were instructed to reconcile their differences, and the consensus code(s) was included for further analysis.

Results

Part I. Comparisons Between VFR-IMC and RoGA

Demographics

Aircrew Information. Similar to other reports (e.g., Goh & Wiegmann, 2002), we found that a higher percentage of those with a private pilot certificate (69.5%) were involved in VFR-IMC accidents in comparison to RoGA accidents (Table 1). RoGA pilots had more advanced certificates (Air Transport Pilot [ATP] – 10.3%, Certified Flight Instructor [CFI] – 15.9%, and Commercial – 33.5%) and were more likely to be instrument rated;

Table 1. Crew Certificate and Rating Percentages for VFR-IMC and RoGA Groups.

Certificate/Rating	VFR-IMC	RoGA
ATP	5.6	10.3
CFI	6.7	15.9
Commercial	27.1	33.5
Private	69.5	51.2
Recreational	0.0	0.1
Student	2.3	9.9
Instrument-		
Airplane	33.0	45.8
Helicopter	2.6	3.7

Note. Pilots may have more than one crew certificate and/or rating.

this is consistent with what others have found (e.g., Goh & Wiegmann, 2002). Perhaps equally important may be the observation that RoGA pilots held a higher number of multiple certificates than the VFR-IMC pilots (Table 2), suggesting that they may be trained to handle more complex situations.

Table 2. Percentage of Certificates Held for VFR-IMC Pilots and RoGA Pilots.

Number of Certificates	VFR-IMC	RoGA
1	89.1	80.7
2	9.8	16.5
3	1.2	2.8
4	0.0	0.1

To determine if there were differences in experience (measured by flight hours) between VFR-IMC accident pilots versus RoGA pilots, we examined the median hours provided in the NTSB reports. An inspection of Table 3 reveals that with one notable exception (Pilot-In-Command [PIC] of make/model of aircraft), RoGA pilots had earned more flight hours across the board.

Table 3. Median Flight Hours for VFR-IMC Pilots and RoGA Pilots.

Flight Hours	VFR-IMC	RoGA
Last 30 Days	10.0	12.0
Last 90 Days	23.0	29.0
PIC Make	131.0	93.0
PIC All[a]	408.0	621.0
Instrument -		
Simulated	10.0	46.0
Actual[b]	62.5	76.0
Total All[a]	731.0	758.0

[a]The "PIC All" and "Total All" flight hours excluded any cases with a blank or where the database had a value of "0."

[b]Only the hours in which it was indicated that the pilots possessed an instrument rating were included.

However, the hours flown in the last 30 and 90 days did not reveal large differences, suggesting that recent flight experience alone cannot explain differences observed between the groups.

Phase of Flight. The highest percentage of accidents for the VFR-IMC group occurred during the cruise phase of flight, whereas most RoGA accidents occurred during the landing phase (Figure 1). Less notable differences were observed during takeoff and maneuvering flight, with the former being more prevalent during RoGA and the latter during VFR-IMC.

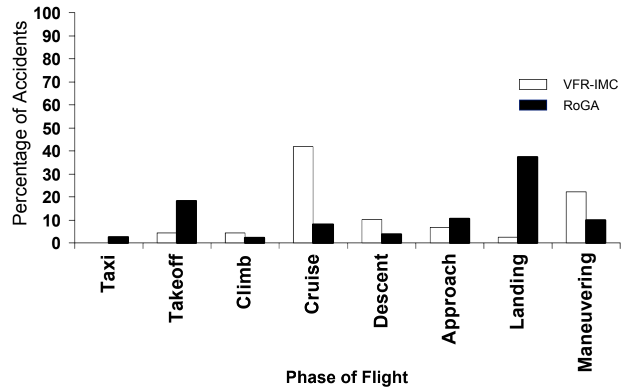

Figure 1. Phase of flight percentages for VFR-IMC and RoGA accidents.

Physical/Geographic Characteristics. Relatively fewer VFR-IMC accidents occurred during daylight conditions (64.6%) than RoGA accidents (86.7%; Figure 2). In contrast, although comparatively fewer accidents occurred during the night, the proportion of VFR-IMC accidents was noticeably larger than RoGA.

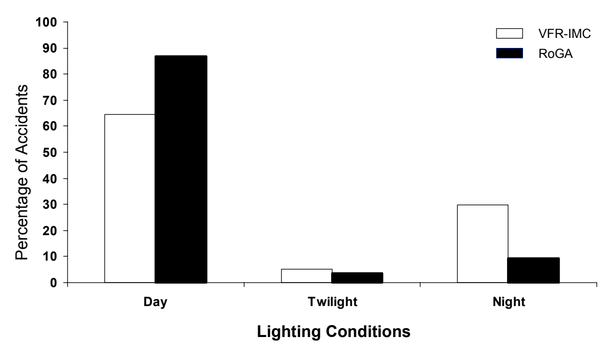

Figure 2. Percentage of accidents occurring during day, twilight, and nighttime conditions for VFR-IMC and RoGA accidents.

Similar to previous accident studies (Goh & Wiegmann, 2002), we found that the injury severity for VFR-IMC accidents was greater than for RoGA (Figure 3). That is, fatalities were much more common in VFR-IMC (80.3% vs. 18.8%). Even more important, there were 954 fatalities associated with the 609 VFR-IMC accidents. For the 18,528 RoGA accidents, there were 6,211 fatalities. Therefore, it was not a surprise to find that aircraft damage that was sustained in a VFR-IMC accident was far greater than for RoGA.

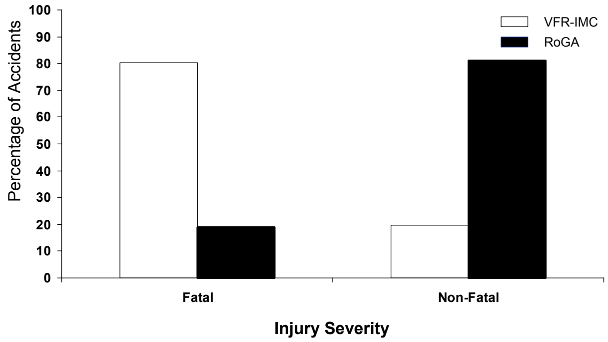

Figure 3. Injury severity percentages for VFR-IMC and RoGA accidents.

Human Error

Unsafe Acts of the Operator. Skill-based errors were more prevalent in RoGA than in VFR-IMC (odds ratio = 4.167, χ^2 = 332.531, p <.001). Not surprisingly, however, VFR-IMC pilots were more likely to commit a decision error (odds ratio = 2.062, χ^2 = 77.961, p <.001); experience a perceptual error (odds ratio = 3.179, χ^2 = 118.350, p <.001); and commit a violation (odds ratio = 29.960, χ^2 = 2454.198, p <.001), see Figure 4. Note that percentages across all unsafe acts will not sum to 100 due to multiple unsafe acts within an accident.

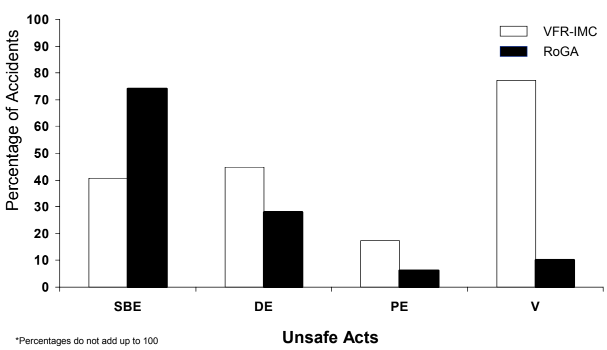

Figure 4. Percentages of unsafe acts for VFR-IMC and RoGA accidents.

Preconditions for Unsafe Acts. Figure 5 reveals that VFR-IMC pilots were more likely to experience an adverse mental state (odds ratio = 2.906, χ^2 = 79.333, p <.001) and an adverse physiological state (odds ratio = 12.706, χ^2 = 853.764, p <.001). Although statistically significant, the differences observed between VFR-IMC and RoGA for physical/mental limitations (odds ratio = 1.877, χ^2 = 36.240, p <.001) and crew resource management (odds ratio = 1.566, χ^2 = 14.052, p <.001) were minor.

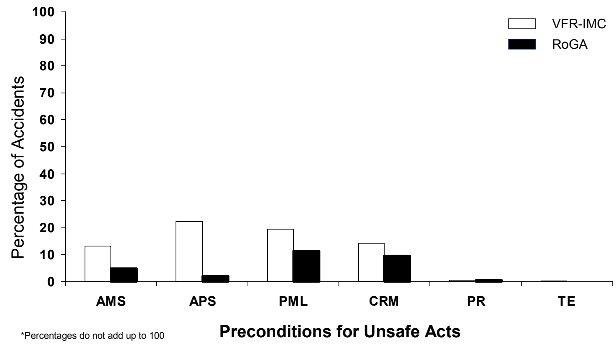

Figure 5. Conditions of the operator percentages for VFR-IMC and RoGA accidents.

In general, multiple factors come together to produce an accident. Given the alternative scenarios that have been offered as precipitating VFR-IMC accidents, we sought to find out if more human error causal factors were prevalent in VFR-IMC accidents. Our analyses revealed that VFR-IMC accidents did have a higher percentage of HFACS codes present in the accident. Assuming that all else is equal (e.g., the depth and detail of the accident investigations are the same), this would seem to suggest that there were more causes and/or factors that were attributable to human error in VFR-IMC scenarios than in RoGA (Table 4). The mean number of codes for RoGA was 1.9, whereas the average for VFR-IMC was 2.8.

Table 4. Percentage of Accidents by the Number of Total HFACS Codes for VFR-IMC and RoGA.

Number of HFACS Codes	VFR-IMC	RoGA
1	14.8	43.8
2	33.3	35.4
3	25.8	14.2
4	14.8	4.5
5	7.4	1.3
6	1.6	0.4
7	1.3	0.1
8	0.8	0.0
9	0.2	0.0

For a better understanding of the specific human error causal factors, we looked at the combination of HFACS codes present within the accidents. As is evident in Table 4, approximately 85.2% of the VFR-IMC and 55.9% of RoGA accidents had two or more HFACS codes. A high number (73.9%) of VFR-IMC accidents received between two and four HFACS codes. The top two most frequent HFACS combinations are presented for VFR-IMC (Table 5a) and RoGA (Table 5b) accidents.

Table 5a. Different Combinations of HFACS Codes Present in VFR-IMC Accidents.

Number of HFACS Codes	VFR-IMC	*N*
2	SBE-V	69
	DE-SBE	30
3	DE-SBE-V	21
	PE-V-APS	13
4	PE-V-APS-PML	12
	PE-V-AMS-APS	7

Note. There were 160 different combinations present in the accidents with 2 or more codes. The codes listed above do not necessarily depict the order in which they occurred in the accident sequence.

Table 5b. Different Combinations of HFACS Codes Present in ROGA Accidents.

Number of HFACS Codes	RoGA	*N*
2	SBE-SBE	2360
	DE-SBE	1210
3	SBE-SBE-SBE	441
	DE-SBE-SBE	370
4	SBE-SBE-SBE-PML	79
	DE-SBE-SBE-SBE	78

Note. There were 495 different combinations present in the accidents with 2 or more codes. The codes listed above do not necessarily depict the order in which they occurred in the accident sequence.

For accidents where two HFACS codes were assigned, SBEs were more frequently combined with Vs for the VFR-IMC group than any other combination. For RoGA, the most frequent dual combination was SBE-SBE. DE-SBE was the second-most frequent combination for both accident groups.

When 3 codes were assigned, the most frequent trio for VFR-IMC was DE-SBE-V versus SBE-SBE-SBE for RoGA. PE-V-APS-PML was the most frequent set when 4 HFACS codes were identified within VFR-IMC. For RoGA, the most frequent occurring combination was 4 codes that consisted of 3 SBEs paired with a PML or 3 SBEs paired with a DE.

In many VFR-IMC accidents, a violation was coded, which may be a characteristic of this type of accident. Nonetheless, these findings illustrate the various human error complexities that surround a VFR-IMC accident versus those that occur in other conditions. To further understand the nuances of VFR-IMC accidents, we focused several analyses on these accidents solely.

Part II. In-Depth Examination of VFR-IMC Accidents Demographics

Pilot Characteristics. When pilot age for the VFR-IMC accidents was divided into five groups (≤30, 30.1 – 40, 40.1 – 50, 50.1 – 60, and 60.1≥), those 30 years and younger had fewer accidents by comparison (Table 6). However, it is possible that this is simply an artifact of fewer pilots for this age group in general. The remaining accidents were distributed fairly evenly across the four age groups.

Table 6. VFR-IMC Age Group Distributions.

Age Groups	*N*	Percent
≤30	58	9.6
30.1 – 40	104	17.2
40.1 – 50	154	25.4
50.1 – 60	136	22.4
60.1≥	154	25.4

Perhaps more important, injury severity was evenly distributed across age groups (Table 7).

Table 7. Percentage of Fatal vs. Non-Fatal for Each VFR-IMC Age Group.

Age Groups	Non-Fatal	Fatal
≤30	27.6	72.4
30.1 – 40	15.4	84.6
40.1 – 50	20.8	79.2
50.1 – 60	22.1	77.9
60.1≥	15.6	84.4

As mentioned previously, pilots with fewer flight hours have been found to be involved in many fatal weather-related accidents. Indeed, Craig (2001) referred to the range of flight hours between 50 and 350 as the "killing zone." We found some support for Craig's hypothesis in that nearly one-third of the VFR-IMC fatal accident pilots' total hours fell within this range.

To determine what the VFR-IMC pilots may have understood about the conditions that they were depart-

ing into, we examined the flight plans that were filed and the type of weather briefing they received. In doing this, we discovered that the majority (80.0%) did not file a flight plan, and only 16.7% had a VFR plan on file (Table 8).

Table 8. Types of Flight Plans Filed for the VFR-IMC Accidents.

Flight Plan Filed	*N*	Percent
Company VFR	14	2.3
IFR	18	3.0
None	487	80.0
Unknown	1	0.2
VFR/IFR	1	0.2
VFR	88	14.4

It may seem unusual to see an IFR flight plan filed for a VFR-IMC accident. Each of the situations had special nuances that explain this "anomaly." For example, an IFR flight plan was filed but cancelled prior to the accident, an IFR flight plan was filed but the pilot was not instrument-rated, or the pilot requested an IFR flight plan in the air and was waiting for an IFR clearance.

The NTSB was only able to document that pilots received some type of weather briefing in 42.1% of the VFR-IMC accidents (Table 9). For the most part, however, it was unknown whether the remaining 57.2% of the pilots had received any weather information.

Table 9. Documented Weather Briefings for VFR-IMC Pilots.

Weather Briefing	Percent
Abbreviated	0.5
Full	31.3
Partial-limited by briefer	1.0
Partial-limited by pilot	9.3
Unknown	57.2

Table 10. Top 3 NTSB Subject Codes for Each Unsafe Act Within the VFR-IMC Accidents.

Unsafe Acts	Percent[a]
Skill-based Errors	
Clearance	19.4
Altitude/Clearance	19.0
Aircraft Control	16.1
Decision Errors	
VFR Flight into IMC	43.0
In-Flight Planning/Decision	20.2
Weather Evaluation	6.8
Perceptual Error	
Aircraft Control	77.5
Altitude	5.4
Descent	2.7
Violations	
VFR Flight into IMC	85.9
Flight into Known Adverse Weather	3.6
Design Stress Limits of A/C	3.2

[a]Percent of each subject code within each of the unsafe acts (e.g. – 19.4% of the SBEs involved clearance).

Table 11. Percentage of Modifier Codes for Accidents With VFR Flight Into IMC as a Subject Code and Assigned as a Decision Error and/or Violation.

Modifier Code	Decision Error *N* (%)	Violation *N* (%)
Unknown	2 (1.3)	5 (1.1)
Attempted	2 (1.3)	80 (17.5)
Continued	6 (4.0)	221 (48.3)
Inadvertent	135 (89.4)	2 (0.4)
Intentional	—	60 (13.1)
Inadequate	—	1 (0.2)
Initiated	—	28 (6.1)
Performed	—	57 (12.4)
Encountered	6 (4.0)	4 (0.9)

Human Error

Unsafe Acts of the Operator. Skill-based errors were associated with 40.6% of the VFR-IMC accidents. A more detailed investigation revealed that the main SBE was failure to maintain clearance from terrain or obstacles (Table 10). Decision errors were associated with 44.7% of the accidents. Not surprisingly, the primary DE was inadvertent VFR flight into IMC (Table 11), followed by in-flight planning/decision-making. Perceptual errors were found in 17.4% of the VFR-IMC accidents and primarily involved the inability to maintain aircraft control. This could be the result of pilots experiencing spatial disorientation. Violations were associated with 77.2% of the VFR-IMC accidents. This was not unexpected as the majority of these were *continued* VFR flight into IMC (Table 11), followed by flight into known adverse weather.

Preconditions for Unsafe Acts. VFR-IMC pilots experienced an adverse mental state within 13.3% of the accidents. More specifically, the pilot's overconfidence in personal ability was at the top of the list. Adverse physiological states were apparent in 22.3% of accidents. In nearly all (92.1%) of the accidents where an adverse physiological state was a factor, the precursor was spatial disorientation. Physical/mental limitation factors played a role in 19.4% of the VFR-IMC accidents, with lack

of experience present in the vast majority of these situations. Crew resource management factored into 14.3% of the accidents, of which preflight planning and preparation accounted for 67.4% of these accidents. Personal readiness and TEs were factors in less than 1% of the accidents. Table 12 lists the top 2 NTSB subject codes for each precondition for unsafe acts within the VFR-IMC accidents.

Table 12. Top 2 NTSB Subject Codes for Each Precondition for Unsafe Acts Within the VFR-IMC Accidents.

Preconditions for Unsafe Acts	Percent[a]
Adverse Mental States	
Overconfidence in Personal Ability	31.8
Pressure	28.4
Adverse Physiological States	
Spatial Disorientation	92.1
Became Lost/Disoriented	5.0
Physical/Mental Limitations	
Lack of Experience	93.0
Lack of Certification	3.1
Crew Resource Management	
Preflight Planning/ Preparation	67.4
Preflight Briefing Service	18.0

[a]Percent of each subject code within each of the preconditions for unsafe acts (e.g. – 92.1% of APS involved spatial disorientation).

Discussion

Weather-related accidents, particularly those associated with VFR flight into IMC, continue to be a threat to GA safety, given that 80% of the VFR-IMC accidents resulted in a fatality. This outcome is not unique to the U.S., as Batt and O'Hare (2005) have found that 76% of the GA accidents involving VFR flight into IMC in Australia also resulted in at least one fatality.

The goal of this study was to further understand the cause of VFR flight into IMC by examining demographic and human factors associated with these types of accidents. Particular emphasis was placed on how the pattern of human error may differ between those accidents associated with VFR flight into IMC and those in the rest of GA.

Similar to other reports (Goh & Wiegmann, 2002), we found that the majority of VFR-IMC accidents involved non-instrument rated private pilots. Perhaps not altogether surprising, it was interesting to note that in comparison, pilots involved in other types of GA accidents (i.e., RoGA) had more certificate ratings overall and were more likely to be instrument rated.

This is not to say that non-instrument rated pilots are prone to VFR flight into IMC. Assuming flights are properly planned and weather adequately evaluated, even the non-instrument rated pilot should be able to fly safely. However, we should recognize that non-instrument rated pilots are taught to avoid weather and have limited flight training in simulated instrument conditions. Arguably, this does not prepare non-instrument rated pilots if they find themselves in true instrument meteorological conditions (Michael Lenz, personal communication).

The next logical question is whether or not pilots associated with VFR flight into IMC even knew they were about to encounter hazardous weather. What we do know is that all pilots flying out of the airport area are required to educate themselves about the weather conditions and forecasts for the area (FAA, 2006). Therefore, it seems reasonable to expect that even pilots involved in VFR flight into IMC accidents were knowledgeable of existing weather conditions.

Unfortunately, we do not know if the 57.2% of the pilots that were involved in VFR-IMC accidents actually obtained a weather briefing. Still, at least 42.1% did get a weather briefing, according to the accident reports, and theoretically understood the likelihood of an adverse weather encounter en route. In fact, it is quite possible that the number of pilots obtaining some sort of weather information prior to flight is higher than reported by the NTSB, given that many pilots examine weather on the Internet or listen to an Automatic Terminal Information Service (ATIS) briefing — something that neither we nor the NTSB could confirm. When taken together, it is difficult to know exactly what the pilots actually knew, and perhaps more importantly, understood regarding the conditions they were departing into at the time.

Although the accident data examined here would seem to suggest that preflight planning and preparation play an important role in a number of VFR-IMC accidents, it is difficult to know from the accident record exactly what weather information the pilot obtained before and during flight. As a result, we are currently conducting a follow-up study that involves interviewing GA pilots that encounter adverse weather. Ideally, by interviewing pilots directly, we hope to obtain a better understanding of GA pilot weather decisions.

Regardless of whether or not pilots involved in VFR-IMC accidents received and understood the weather they encountered, most of the accidents occurred en route, which adds further complexity to the issue of what pilots knew about the weather at that time. Previous research (Knecht, in press) has documented the range of weather products and providers that pilots use in flight planning and suggests that weather-related accidents are, at least in part, information-driven. GA aircraft on cross-country flights travel at speeds that expose them to the limits of pre-departure forecasting. It is certainly plausible that weather at pilots' destinations may be worse than fore-

casted (Knecht & Lenz, in review). Because of this, these pilots are exposed to changing weather conditions over extended space and time.

In 2005, the NTSB compared GA weather-related accident flights with a matched control group of non-accident flights and found that pilots on flights of more than 300 nautical miles (nm) were 4.7 times more likely to be involved in an accident than pilots on flights of 50 nm or less.

It is important to note that systems and products that provide timely and accurate weather information to pilots are expected to be a key part of any intervention aimed at reducing VFR-IMC. One such product is en route weather information available from Flight Watch. Unfortunately, the extent of its utilization and other weather products used by GA pilots varies widely.

Although weather is an obvious concern when discussing VFR-IMC, flight experience has also been proposed as an explanation for a number of fatal weather-related accidents (Craig, 2001). Some support of Craig's hypothesis was found in the data presented here; in that, nearly one-third of the VFR-IMC fatal accident pilots' total hours fell within this range (50 to 350 hours) – although somewhat lower than the percentage Craig reported. The reason for the lower percentage in this study may be because we have focused solely on VFR-IMC accidents, which are a subset of all weather-related accidents. Thus, when we look at weather-related accidents as a whole, the percentage of fatal accidents is likely to increase.

Often going hand-in-hand with experience, pilot age may be a viable explanation for VFR-IMC accidents. However, our analyses revealed little differences between the age groups. Interestingly, the NTSB (2005) suggested that age at certification is a much better predictor regarding weather-related accident involvement than age at the time of the accident. In fact, they argue further that pilots who begin their flying career while young are less likely to be involved in a weather-related accident than those who begin later. They posit that for those that enter aviation early in life, there may be differences in motivation for flying and plans for aviation as a career.

As seen elsewhere, (e.g., Goh & Wiegmann, 2002) the majority of the VFR-IMC accidents occurred during the cruise phase of flight. After all, at least during the take-off phase of flight, VFR conditions likely prevail. To some extent, the same can be said for the landing phase of flight. Typically, it is during cruise that a pilot is more likely to encounter IMC and be forced to make a decision to continue or divert to an alternate landing site.

Additionally, we found a higher proportion of VFR-IMC accidents occurred at night. Therefore, it is possible that pilots may not have recognized or have been unaware of the severe weather in their path.

Obviously, variables such as age, experience, training, weather briefings, and phase of flight can prove useful in the development and targeting of intervention strategies. For instance, it can be argued that one way to reduce accidents associated with VFR flight into IMC is to provide pilots with better in-flight weather information through enhanced displays and datalinks.

However, the solution to many human factors issues facing GA pilots today may require more than traditional approaches such as technological improvements. After all, no single intervention will likely be the panacea, and in some cases may actually lead to more problems than it resolves. For example, Beringer and Ball (2004) demonstrated that when deciding to fly into, under, or through the weather, pilots were more likely to do so with avionics that had higher resolution. Likewise, Williams, Yost, Holland, and Tyler (2002) found that pilots admitted that they would be more willing to take a chance and risk flying closer to the weather when using the displays than without. They also found that the increase in avionics in the cockpit caused pilots to rely more on the equipment than their basic flying skills, in addition to more "heads-down" time in the cockpit.

So while technological approaches are appealing, they may provide pilots with an overconfidence of how close they can get to weather and to navigate through it. On the other hand, Ball (in review) found that some pilots can be trained to use weather information strategically as a means to avoid, rather than to tactically navigate through, dangerous environments. Clearly, weather information, with the right training and understanding, can benefit GA pilots at all levels – although some degree of caution should be employed when flying in weather.

Boatman (2001) noted that pilots are taught to be confident when flying. For less-experienced pilots who may underestimate the risks of flying in marginal VFR conditions, overconfidence in their abilities may conflict with good decisions in these circumstances. Indeed, we found that pilots' overconfidence in their personal ability was a factor in VFR-IMC accidents.

For years, government and private organizations have attempted to educate pilots to make informed decisions when it comes to flying in weather. Work by the FAA (2005) provides guidance to pilots through a decision-making framework. It discusses three steps (perceive, process, and perform) during flight. AOPA-ASF has a variety of free on-line courses that pilots can take that educate them on different weather topics.

In 1989, the NTSB identified many of the same causes and factors that were found to be an issue in our analyses. Given the similarities, one might generalize that the intervention strategies that have been put in place for nearly the past 2 decades have been ineffective.

Informing pilots of the pitfalls of VFR-IMC with the hope of educating them about the consequences of taking risks, the importance of gaining a clear understanding of the weather within their flight path from departure to landing, and reminding pilots that it is their responsibility to be aware of weather when leaving the airport traffic area are integral steps to stop the chain of events that can result in a VFR flight into IMC accident.

Though the suggestion may seem radical, one solution proposed during a brainstorming activity was to require all pilots to obtain a weather briefing and to file a flight plan before departure. Limiting this requirement to those leaving the airport traffic pattern would help ensure that prior to taking off all pilots were briefed on the available weather. This assumes that all pilots have the requisite skills to process the weather information they are provided.

Knecht, Harris, and Shappell (2005) described the many findings surrounding the difficulties associated with pilots assessing the risk of weather. While trying to ascertain the influence of a variety of motivators for why GA pilots would depart into marginal conditions, they found that personality alone did not influence take-off. Social-cognitivists (Mischel & Shoda, 1995) have long argued that understanding personality within a context is the best predictor for behavior. When money was not manipulated to be a motivator, Knecht, et al. (2005) found the interactive effect of visibility and ceiling encouraged pilots to stay on the ground. One caveat to consider is half of their participants were instrument-rated, so that additional knowledge may have assisted decision-making. Nonetheless, the authors concluded that two groups of weather-risk pilots emerged: 1) those without an understanding of the risks of weather, and 2) pilots who have little instrument time. Ensuring that pilots have and understand the weather before departing sounds like a simple solution, but how can that be done consistently? It is plausible that if all pilots are required to document weather awareness prior to departure and learn how to perceive and process weather, this additional information could reduce accidents. Knecht and Lenz (in review) point out that VFR pilots are trained to avoid bad weather; therefore, when they find themselves in the midst of poor conditions, they are inexperienced in navigating their way through it. As noted, the FAA has made guidance available to pilots about the complications and threats of flying in weather.

We now have a better understanding of the human error associated with VFR-IMC accidents. But how can this information help us prevent these accidents from occurring in the first place? In a separate study, we are examining the various initiatives in place that are aimed at reducing VFR-IMC accidents. We plan to present the various initiatives with the complementing descriptions of the errors that they are aimed at reducing.

The Next Step …

Clearly, the data described here paint a more complete picture of VFR flight into IMC and offer a glimpse at potential interventions to address this threat to GA safety. However, many questions remain. For instance, which of the interventions suggested would have the greatest impact on VFR flight into IMC? Are similar programs currently underway within the FAA that can be leveraged in this regard? Are there gaps in existing GA safety programs that need to be addressed if we are to reduce VFR flight into IMC?

These are but a few of the questions that must be answered if the prevalence of VFR-IMC accidents is to be reduced. The next step in any system safety process after the hazard has been identified and sufficiently defined is the identification, development, and assessment of putative interventions. To some extent, this effort has already begun, as described above. However, a second effort is currently underway that will use the Human Factors Intervention matriX (HFIX) to identify existing safety programs that have been implemented in civil aviation that can be modified or redirected to address VFR flight into IMC and other threats to GA.

As depicted in Figure 6, HFIX pits the HFACS causal categories, as identified within HFACS (e.g., decision errors, skill-based errors, perceptual errors, and violations), against five common approaches to accident intervention identified within the literature (Shappell & Wiegmann, 2006). Specifically, HFIX employs intervention approaches that target change within the 1) organization, 2) human, 3) technology, 4) mission, and 5) physical environment. Whereas it is not uncommon for organizations to focus on one or two approaches, depending on the makeup of its staff, HFIX looks at the breadth of interventions across all five approaches.

	Organizational/ Administrative	Human/ Crew	Technology/ Engineering	Task/ Mission	Operational/ Physical Environment
Decision Errors					
Skill-based Errors					
Perceptual Errors					
Violations					

Figure 6. The "Human Factors Intervention matriX" (HFIX).

Our current effort involves mapping existing and prospective interventions identified by programs such as Joint Safety Intervention Teams, Joint Safety Action Teams, the National Aviation Research Plan, and other resources into the HFIX matrix. Using HFIX, it will be possible to identify which programs would significantly reduce a given type of human error and where gaps in the current safety strategy exist. The goal is to provide the FAA with a ready reference of interventions that target specific types of human error (e.g., VFR flight into IMC), rather than a type of accident (controlled flight into terrain) or general error form (e.g., decision errors), as has been done in the past. Ideally, this data-driven intervention approach will target specific human errors known to adversely affect general aviation safety. Ultimately, this will lead to changes that will improve safety and decrease fatalities.

References

Aircraft Owners and Pilots Association Air Safety Foundation (2006). 2006 Nall report: Accident trends and factors for 2005. Retrieved January 5, 2006 from www.aopa.org/asf/publications/nall.html.

Ball, J. (in review). The impact of training on general aviation pilots' ability to make strategic weather-related decisions. Washington, DC: Federal Aviation Administration Office of Aerospace Medicine.

Batt, R. & O'Hare, D. (2005). General aviation pilot behaviours in the face of adverse weather. (B2005/0127). Civic Square, ACT: Australian Transport Safety Bureau.

Beringer, D. & Ball, J. (2004). The effects of NEXRAD graphical data resolution and direct weather viewing on pilots' judgments of weather severity and their willingness to continue a flight. (DOT/FAA/AM-04/5). Washington, DC: Federal Aviation Administration Office of Aerospace Medicine.

Boatman, J. (2001). Ounce of prevention: Shades of gray. Retrieved April 6, 2006 from www.aopa.org/pilot/features/2001/ounces0110.html.

Craig, P. (2001). Continued VFR into IFR operations. In The killing zone: How and why pilots die. (25-70). New York: McGraw-Hill.

Detwiler, C., Hackworth, C., Holcomb, K., Boquet, A., Pfleiderer, E., Wiegmann, D., & Shappell, S. (2006). Beneath the tip of the iceberg: A human factors analysis of general aviation accidents in Alaska versus the rest of the United States. (DOT/FAA/AM-06/7). Washington, DC: Federal Aviation Administration Office of Aerospace Medicine.

Federal Aviation Administration (2005). General aviations pilot's guide to preflight weather planning, weather self-briefings, and weather decision making. Retrieved August 24, 2006, from www.faa.gov/pilots/safety/media/ga_weather_decision_making.pdf.

Federal Aviation Administration (2006). Air traffic and general operating rules. Retrieved September 14, 2006 from www.airweb.faa.gov/Regulatory_and_Guidance_Library/rgFAR.nsf/0/8FF69D2EEBA22CF9852566CF00613B69?OpenDocument &Highlight=91.103.

Goh, J. & Wiegmann, D. (2001). Visual flight rules flight into instrument meteorological conditions: An empirical investigation of the possible causes. *International Journal of Aviation Psychology, 11*(4), 359-79.

Goh, J. & Wiegmann, D. (2002). Human error analysis of accidents involving visual flight rules flight into adverse weather. *Aviation, Space, and Environmental Medicine, 78*(8), 817-22.

Knecht, W. (in press). Use of weather information by general aviation pilots, Part I, quantitative: Reported use and value of providers and products. Washington, DC: Federal Aviation Administration Office of Aerospace Medicine.

Knecht, W., Harris, H., & Shappell, S. (2005). The influence of visibility, cloud ceiling, financial incentive, and personality factors on general aviation pilots' willingness to take off into marginal weather, Part I: The data and preliminary conclusions. (DOT/FAA/AM-05/7). Washington, DC: Federal Aviation Administration Office of Aerospace Medicine.

Knecht, W. & Lenz, M. (in review). General aviation weather-related, non-fatal incidents: Part I- Quantitative analysis of possible causes using aviation safety reporting system (ASRS) data. Washington, DC: Federal Aviation Administration Office of Aerospace Medicine.

Mischel, W. & Shoda, Y. (1995). A cognitive-affective system theory of personality: Reconceptualizing situations, dispositions, and invariance in personality structure. *Psychological Review*, 102(2), 246-68.

National Aviation Safety Data Analysis Center (n.d.) NTSB Aviation Accident and Incident Data System retrieved on July 5, 2006, from www.asias.faa.gov/portal/page?_pageid=56,86203,56_86223:56_86227:56_96442&_dad=portal&_schema=PORTAL. See NTSB Aviation Accident and Incident Data System (NTSB).

National Transportation Safety Board. (1989). General aviation accidents involving visual flight rules into instrument meteorological conditions (NTSB/SR-89/01). Washington, D.C.

National Transportation Safety Board. (2005). Risk factors associated with weather-related general aviation accidents. (NTSB/SS-05/01). Washington, D.C.

Parson, S. (2006). Weather decision making for GA pilots. *FAA Aviation News*, 45(4), 8-12.

Reason, J. (1990). Human Error. New York: Cambridge University Press.

Shappell, S. & Wiegmann, D. (2006). Developing a methodology for assessing safety programs targeting human error in aviation. (DOT/FAA/ AM-06/24). Washington, DC: Federal Aviation Administration Office of Aerospace Medicine.

Shappell, S. Detwiler, C., Holcomb, K., Hackworth, C., Boquet, A., & Wiegmann, D. (2007). Human error and commercial aviation accidents: A comprehensive, fine-grained analysis using HFACS. *Human Factors, 49*(2), 227-42.

Wiegmann, D., Faaborg, T., Boquet, A., Detwiler, C., Holcomb, K., & Shappell, S. (2005). Human error and general aviation accidents: A comprehensive, fine-grained analysis using HFACS. (DOT/FAA/AM-05/24). Washington, DC: Federal Aviation Administration Office of Aerospace Medicine.

Wiegmann, D. & Shappell, S. (2003). A human error approach to aviation accident analysis: The human factors analysis and classification system. Burlington, VT: Ashgate.

Williams, K., Yost, A., Holland, J., & Tyler, R. (2002). Assessment of advanced cockpit displays for general aviation aircraft – The capstone program. (DOT/FAA/AM-02/21). Washington, DC: Federal Aviation Administration Office of Aerospace Medicine.